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THE CHANNELED SCABLANDS OF THE COLUMBIA PLATEAU

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OUTLINE

DEFINITION OF "SCABLAND"

The terms "scabland" and "scabrock" are used in the Pacific Northwest to describe areas where denudation has removed or prevented the accumulation of a mantle of soil, and the underlying rock is exposed or covered largely with its own coarse, angular débris. The largest areas of scabland are on the Columbia Plateau in Wash-

ington, north of Snake River. These scablands have a history which is believed to be unique. The prevailing feature of their topography is indicated in the term here used: channeled scablands.[1] They are scored by thousands of channels eroded in the underlying rock. The plateau in Washington, north of Snake River, has a total area of about 12,750 square miles, of which at least 2,000 square miles is channeled scabland. The scabland is widely distributed over the region in linear tracts among maturely dissected hills which bear the loessial soil (wheat lands) of the plateau.

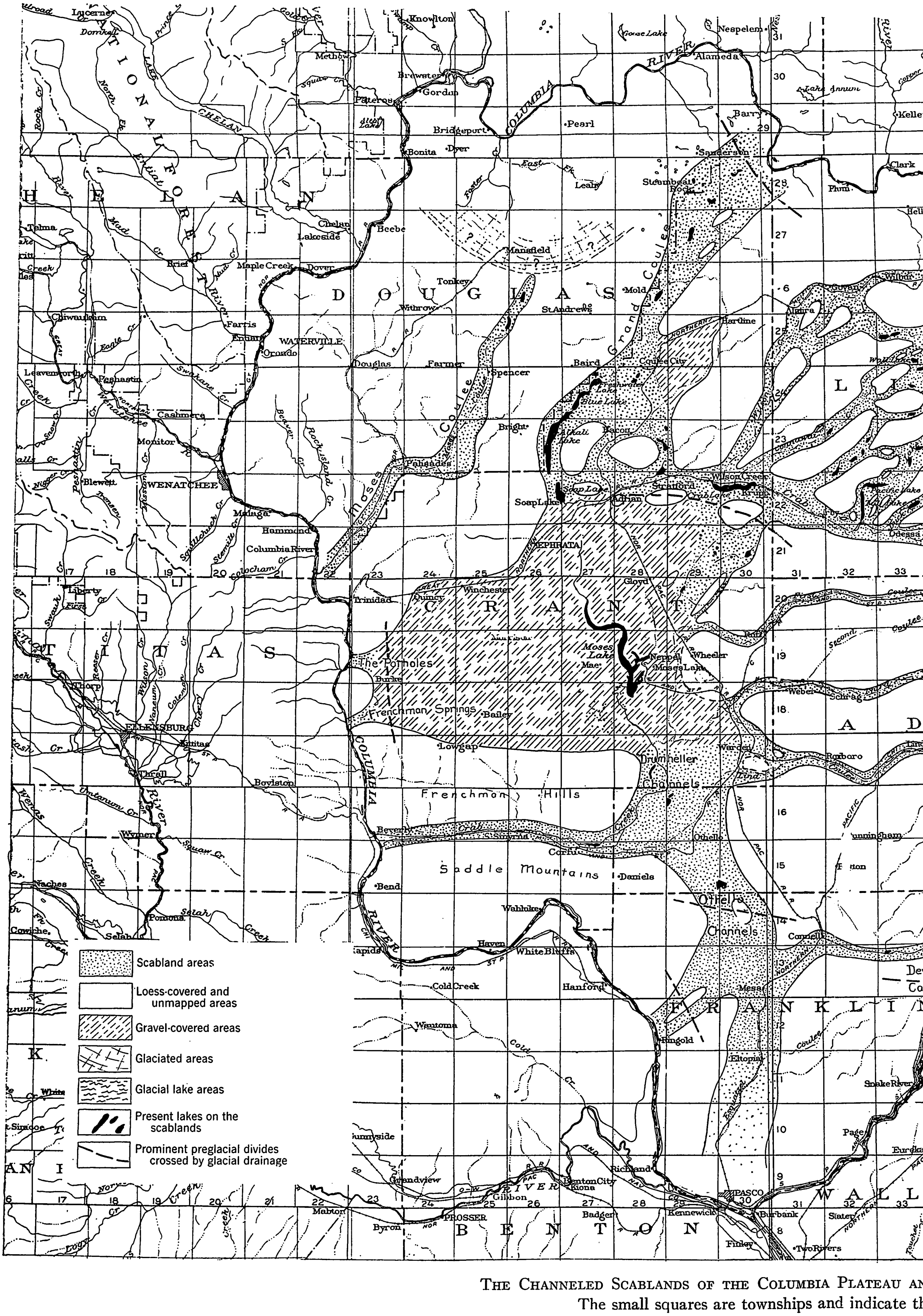
PHYSIOGRAPHIC RELATIONS OF THE CHANNELED SCABLANDS

The following features and relations of the scablands exist in all tracts. They must form the basis of any interpretation for the origin of channeled scabland. The map should be examined as this list is read.

1. Scabland tracts are developed invariably on or in the Columbia basalt formation.
2. Scabland tracts are invariably lower than the immediately adjacent soil-covered areas.
3. Scabland tracts are invariably elongate.
4. The elongation of scabland tracts is with the dip slope of the underlying basalt flows. There are eight known exceptions to this rule,[2] all minor affairs so far as length is concerned.
5. Scabland tracts, considered as units, invariably have continuous gradients.
6. Scabland tracts are invariably bounded by maturely eroded topography.

[1] An earlier paper on this subject was published by the writer in the *Bulletin of the Geological Society of America*, Vol. XXXIV (1923), pp. 573–608. The study on which it was based involved about a 1,000-mile traverse of the plateau. Since then, the writer has studied the plateau more thoroughly, having added more than 2,000 miles to the previous total traverse. Much more detailed information and several modifications of the earlier interpretations justify the appearance of a second paper on the subject. The accompanying map (Plate III) is based on a field examination of every scabland there indicated. In a few places the boundaries are inferred (dashed lines) but future work will hardly do more than make minor changes or additions.

[2] A part of Othello Channels, a part of Drumheller Channels, at Palisades and near Spencer in Moses Coulee, at Soap Lake and near Bacon in Grand Coulee, 6 miles south of Almira on Wilson Creek, and at Long Lake in Spring Coulee.



The Channeled Scablands of the Columbia Plateau an
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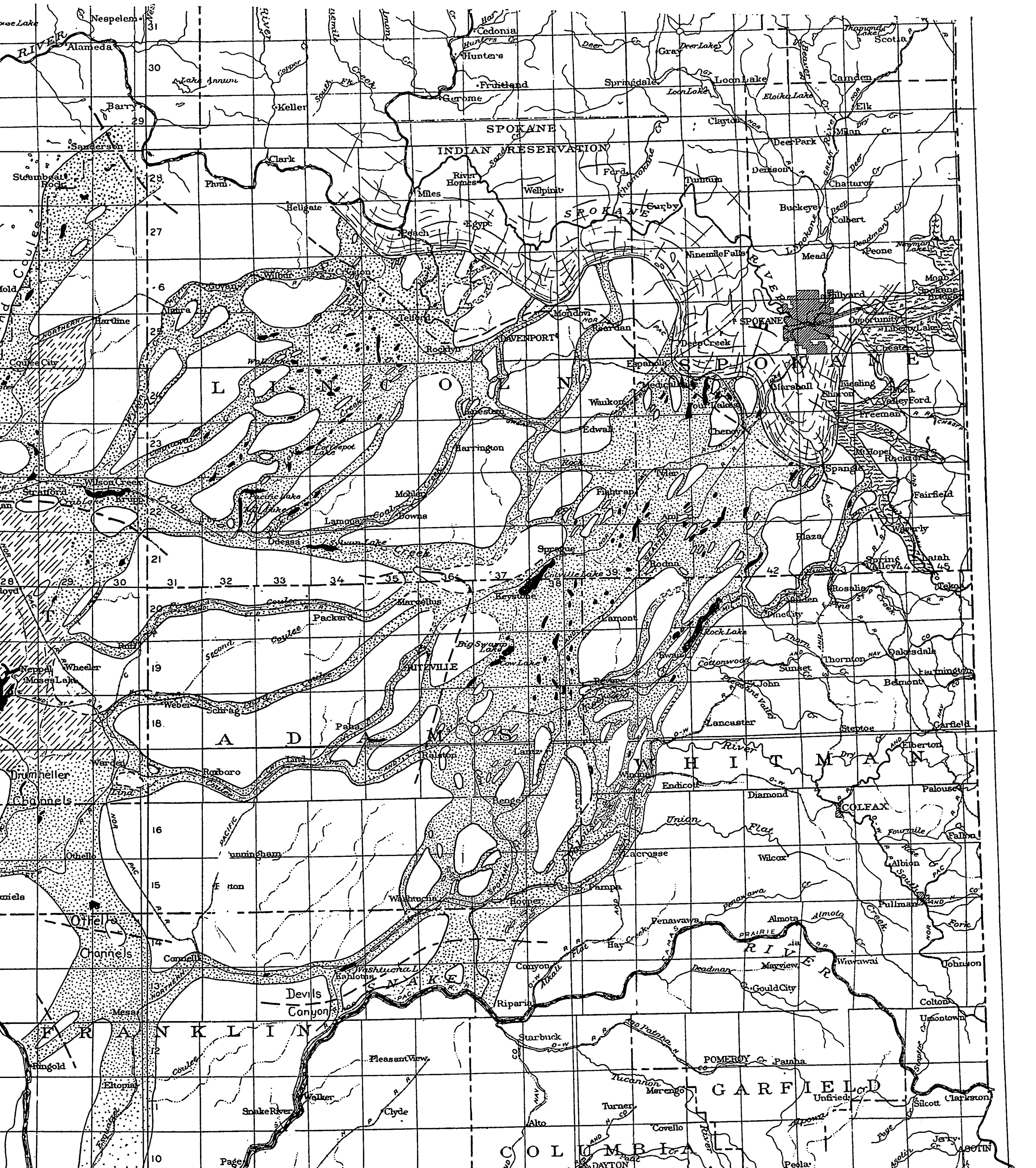

ABLANDS OF THE COLUMBIA PLATEAU AND THEIR ASSOCIATED FEATURES
all squares are townships and indicate the scale of the map

7. Scabland tracts are developed in pre-existing drainage lines of the mature topography.[1]

8. Scabland tracts are connected with each other.[2]

9. (*a*) The areas surrounded by scabland invariably have the dendritic drainage pattern, mature topography and loessial soil of the plateau. (*b*) They are almost invariably elongate with the scabland tracts. (*c*) They commonly have steep marginal slopes descending from 50 to 200 feet to the scabland. These slopes are almost invariably in loess. Slopes of 30° to 33° are not uncommon. They are much younger topographically than the slopes of the valleys among these mature hills.

10. Scabland tracts with steep gradient are narrow, while those with gentle gradient are wide.

11. The pattern of scabland tracts, where hills of the older topography are isolated in them, is anastomosing or "braided."

12. Scabland tracts invariably contain "channels." These are gorges or canyons or elongated basins eroded in the basalt. The channels are invariably elongate in parallelism with the tract as a whole and, in most cases, the channel pattern is anastomosing or braided.

13. (*a*) Scabland tracts invariably bear discontinuous deposits of basaltic stream gravel. (*b*) These deposits invariably contain a small proportion of pebbles and cobbles of rock foreign to the plateau. (*c*) These deposits invariably rest on an eroded, scabland surface of the basalt. (*d*) They commonly lie on the down-gradient side of eminences in the scabland.

14. (*a*) Scabland tracts invariably bear scattered bowlders of foreign rock. (*b*) The proportion of foreign débris, either the fragments in the gravel or the scattered bowlders, is invariably smaller with increasing distance down-gradient.

15. Scabland tracts are invariably without a mantle of residual soil.

16. Scabland tracts are traceable up-gradient to a narrow basalt plain bordering the south side of Spokane River in the northern

[1] There are many exceptions to this rule, occurring where scabland tracts cross pre-existing divides, but the total length of such is only a small fraction of the aggregate length of all scabland tracts.

[2] Moses Coulee is the only exception.

part of the plateau.[1] This basalt plain bears many glaciated erratic bowlders and some patches of till, but no channeled scabland, no mature topography, and no loessial soil.

17. Only where the minor valleys of the mature topography adjacent to this basalt plain open northward on to the plain are any glacial erratics found in them.[2]

18. There are but ten scabland openings to this basalt plain to the north.

19. Scabland tracts are invariably traceable down-gradient to Snake River on the south or to Columbia River on the west. There are nine places where scabland tracts enter these two streams Only three of them were drainage ways before the scablands were formed.

20. There is no channeled scabland on the plateau in western Idaho or south of Snake River or west of Columbia River.

21. Nowhere in the scablands or the maturely dissected country, during ten weeks of field study, has a till been found, or any deposit of doubtful genesis which could be interpreted more satisfactorily as till than as non-glacial in origin.[3]

GENERALIZED STATEMENT OF THE ORIGIN OF THE CHANNELED SCABLANDS

This unique combination of topographic features of the Columbia Plateau in Washington has only one interpretation consistent with all the foregoing items. The channeled scablands are the erosive record of large, high-gradient, glacier-born streams. The basalt plain records the southern limit reached by the ice sheet from which these streams took origin. Before this glaciation occurred, the entire plateau of Washington was covered with a loessial soil, varying in depth from a few feet to 200 feet. This and the underlying basalt had been eroded to maturity and a network of drainage lines covered it. The major water courses of this mature topography were consequent on the warped surface of the

[1] Grand Coulee and Moses Coulee are exceptions. Grand Coulee opens up-gradient into Columbia River Valley and the upper end of Moses Coulee is obliterated by the drift of a later glaciation.

[2] Exceptions due to a later episode in the history of the region are noted later.

[3] One exception, noted later.

plateau which descends in a general way from the northeast to the southwest.

The ice sheet approached and invaded the plateau from its northern high margin. It barely crossed to the headwaters of the consequent drainage. In places, it did not cross, but by blocking all other escapeways, its waters were forced to cross. By about a dozen different routes, at different altitudes and distributed along more than 150 miles of the ice front, water entered the mature drainage system. The capacity of the pre-existing valleys was wholly inadequate for the volume of most of these streams. Furthermore, gradients were high and the glacial waters eroded enormously, sweeping away the overlying loessial material, crossing low divides and isolating many groups of the maturely eroded hills to produce the anastomosing pattern of the scablands, biting deeply into the basalt to make the canyons and rock basins, and spilling into the Snake and Columbia in three times as many places as the pre-existing drainage had used.

This procedure of glacial streams was unique, so far as the writer is aware. It was unorthodox, at any rate, for no valley trains and but two outwash plains[1] were built on the plateau south of the basalt plain. The stream gravel of the scablands is almost wholly in separate bars.

The conception above outlined is amply sustained by every feature and relationship of the scablands. All other hypotheses meet fatal objections. Yet the reader of the following more detailed descriptions, if now accepting the writer's interpretation, is likely to pause repeatedly and question that interpretation. The magnitude of the erosive changes wrought by these glacial streams is nothing short of amazing. The writer confesses that during ten weeks' study of the region, each newly examined scabland tract reawakened a feeling of amazement that such huge streams could take origin from such small marginal tracts of an ice sheet, or that such an enormous amount of erosion, despite high gradients, could have resulted in the very brief time these streams existed. Not River Warren, nor the Chicago outlet, nor the Mohawk channel,

[1] The Hartline gravel flat and the Quincy basin fill, both in structural depressions in the plateau.

nor even Niagara falls and gorge itself approach the proportions of some of these scabland tracts and their canyons. From one of these canyons alone[1] 10 cubic miles of basalt was eroded by its glacial stream.

THE BASALT PLAIN, NORTH OF THE SCABLANDS AND MATURE TOPOGRAPHY

This physiographic feature extends westward from Spangle for 50 miles along the south side of Spokane River and varies from 3 to 12 miles in width. It is determined by the upper surface of the Columbia basalt formation. It is interrupted in places by short valleys tributary to Spokane River, and the different portions are known as prairies.[2] This plain is bounded on the south by channeled scabland and maturely eroded loessial hills. The differences between it and adjacent broader scablands are not marked, but the loessial hills are in striking contrast with it. These hills which, elsewhere on the plateau, come right to the edge of Snake and Columbia valleys,[3] nowhere overlook the Spokane Valley. They terminate abruptly on the southern margin of this plain. On the plain there is no mature topography and no channeled scabland. There is no area on the plateau like it. The nearest approach to it is the northern portion of Douglas County, back of the Wisconsin terminal moraine. This narrow plain must be the result of conditions which prevailed no farther south.

These conditions can be summed up in one word—glaciation. Deposits of till and many striated erratics have been found in every township examined on it. The till is patchy in distribution. No moraine margins the southern edge of the plain and no good moraine ridges occur on it, though here and there is morainic topography.

The genesis of the plain thus established, the questions of its character before glaciation and the method of its development arise. These are answered clearly when the adjoining mature loessial topography is studied. The larger valleys of this topog-

[1] Upper Grand Coulee.

[2] Paradise Prairie, Sunset Prairie, Indian Prairie, Four Mound Prairie, etc. On the north side of Spokane River are Pleasant Prairie and Five Mile Prairie, also parts of this plain.

[3] With the exception of northern Douglas County.

raphy have been eroded to varying depths into the basalt. The bottoms of such as lead out across the basalt plain to the north are lower among the hills than the general surface of the plain. The profile of the plain, extended back among the hills, cuts their slopes somewhere between hill summits and valley bottoms. And this transection is at the contact of loess on basalt. The ice sheet which covered the plain, therefore, simply removed the upper, weaker formation, and only to a minor extent altered the surface of the basalt formation.

THE MATURE TOPOGRAPHY

This is the dominant type of topography of the Columbia Plateau. The major drainage lines are structurally controlled, but the minor ones constitute a dendritic network. The pattern is eroded largely in a weak sedimentary deposit, chiefly loessial, which overlies the basalt. Maturity is expressed in the complete development of the drainage system, in the reduction of the original surface to valley slopes[1] and in the concavity of the lower part of many of these slopes. This maturity has been developed with reference to the underlying basalt as a base level, for progress of the cycle of erosion in the loess has been very much more rapid. Neglecting the loessial cover, the basalt plateau is in early youth, and will still be when the loess has been entirely removed. Nevertheless, the absence of deep trenches in basalt in the interior of the plateau, similar to Spokane, Columbia, and Snake River valleys about its margin, and the cutting through of the loess has allowed the development of shallow mature valleys in the upper part of the basalt.

The loessial deposit varies in thickness, in some places being only a soil, and in others being 200 feet or more in thickness. It is not all loess. There are places where it is chiefly a residual soil from the basalt, and others where it is a waterlaid sediment.[2] But many widely distributed sections show a succession of loessial deposits,

[1] A few broad, undissected divides are still left. Michigan Prairie, south of Lind, is a good example.

[2] Probably the Ellensburg formation. The Pleistocene Ringold formation, in Franklin County, is younger than the mature topography.

with abundant root and rootlet casts throughout and with reddened upper surfaces of each deposit, aggregating 50 feet or more.[1]

The mature topography is older than the scablands and the basalt plain. Literally hundreds of isolated groups of maturely eroded hills of loess stand in the scablands. Their gentle interior slopes are identical with those far from the scabland tracts. But their marginal slopes, descending to the scablands, commonly are very steep, over large areas amounting to 30° and even 35° (Figs. 1, 2, and 3). These steep slopes are seldom even gullied, except

FIG. 1.—One of a group of loessial hills in the scablands a few miles southwest of Rock Lake. One of the steepened slopes and its alignment are shown. Photo by O. C. Clifford.

where a drainage line leads out from the hill group to the scabland. Where the minor valleys transected by the steep slopes lead backward into the interior of a hill group they are simply hanging valleys.

There are few places where basalt occurs in these steepened slopes. Where present, it is always restricted to the lower part and shows itself in conspicuous ledges.

A very striking and significant feature of the steepened slopes is their convergence at the northern ends of the groups to form great

[1] Near Harrington and near Kahlotus are two excellent cuts which show this very well.

prows, pointing up the scabland's gradient (Figs. 2 and 3). The nose of a prow may extend as a sharp ridge from the scabland to the very summit of the hill. It is impossible to study these prow-

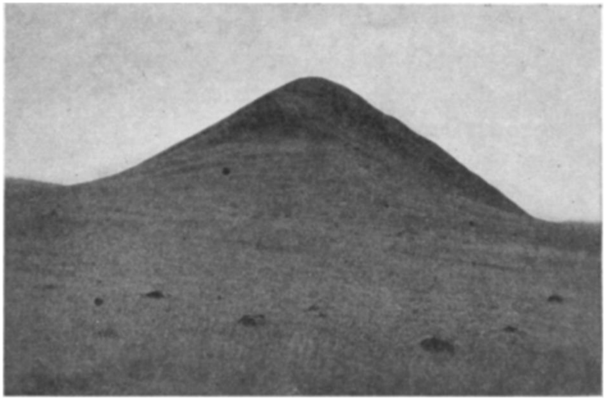

FIG. 2.—An isolated loessial hill on the scabland south of Hooper. The prow of the hill is pointed at the observer. The hill is 180 feet high, more than half a mile long, has a very narrow crest, and sides which slope 35°. It is entirely surrounded by scrubbed basalt. Half a mile to the west is a canyon in the scabland 75 feet deep, with an abandoned waterfall at the head.

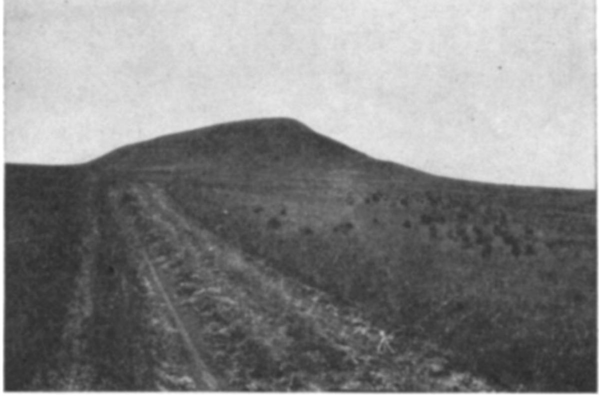

FIG. 3.—The same hill as shown in Figure 2. The prow is at the right. The corresponding steepened slope at the tail of the hill shows at the extreme left. Most of the apparent left slope of the crest is a matter of perspective. Photo by O. C. Clifford.

pointed loessial hills, surrounded by the scarred and channeled basalt scablands, without seeing in them the result of a powerful eroding agent which attacked them about their bases and most effectively from the scabland's up-gradient direction.

DETAILS OF A SCABLAND SURFACE

All scablands are channeled to a greater or lesser extent. These channels are eroded in basalt to depths varying from a few feet to

FIG. 4.—Devils Canyon at mid-length, looking south. A double fall existed here when the canyon was eroded. The island and the eastern part still remain.

hundreds of feet. Commonly there are many shallow channels on each tract. Most tracts also have a few deeper channels, of the proportions of canyons[1] (Figs. 4 and 5). All channels in a tract are intricately interlaced, resulting in a multitude of butte-like hills, knobs, and ridges among them. Few channels have

[1] Upper Grand Coulee (1,000 feet deep), Lower Moses Coulee (900 feet deep), Devils Canyon, Franklin County (500 feet deep), and Palouse Canyon (500 feet deep) are the most noteworthy examples.

accordant grades where they unite or diverge, the bottoms of the shallower ones hanging above the floors of the deeper ones. Many canyoned channels have abandoned cataracts and cascades in them or at their heads.[1] Most canyoned channels have elongated rock basins (see Fig. 6). Even in the shallow channels, basins or pockets in the rock are common. Some of these rock basins clearly were produced by recession of a cataract whose scarp still

FIG. 5.—Devils Canyon near mid-length, looking north. Note the scrubbed basalt ledges above the canyon rim, and the profile of the loessial bluffs, still higher and farther back.

exists.[2] Others were produced by plucking of the columnar basalt in the canyon floors where the gradient was high.[3]

These features of the channeled scablands on the Columbia basalt plateau do not closely resemble any other type of topography.

[1] Dry Falls (400 feet high) in Grand Coulee, The Potholes (350 feet high) south of Trinidad, Frenchman Springs (400 feet high) south of The Potholes, and The Three Devils (600 feet total descent) in Moses Coulee are especially noteworthy.

[2] Deep Lake, below one of the Grand Coulee abandoned falls, has many associated huge potholes, drilled into the basalt at the foot of the falls as they retreated. Each of the two cataracts of "The Potholes," south of Trinidad, has a single elongated rock basin at the foot (Fig. 7).

[3] Rock Lake in Whitman County, Goose Lake in Grant County, Washtucna Lake and Eagle Lake in Franklin County, Pacific Lake and Tule Lake in Lincoln County, Goose Lake in Grant County, Medical Lake, Silver Lake, and Farrington (Fish) Lake in Spokane County, and Big Swamp Lake and Cow Lake in Adams County are examples of hundreds of such basins.

The narrowness and elongation of channels and the continuous gradients of tracts as a whole suggest river valleys but these features are all inherited from pre-existing valleys. Furthermore, some tracts are nearly as broad as they are long. The pattern of channels on a tract, like the pattern of some tracts and their isolated loessial hills, is much like that of great braided streams (Fig. 8).

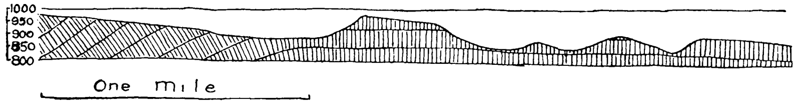

FIG. 6.—Longitudinal profile of the deepest of the Drumheller Channels across the nose of the anticline. Four rock basins are indicated, the largest of which is 75 feet deep.

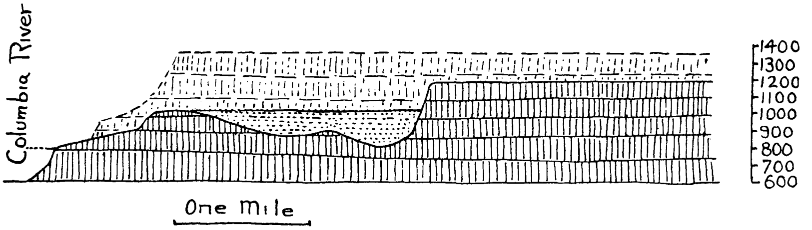

FIG. 7.—"The Potholes," longitudinal profile of the northern half, showing (1) cliff along northern side of the canyon, (2) amount of recession of the falls, (3) elongated rock basin below the falls, (4) great gravel bar along edge of the rock basin, and (5) approximate level of Columbia River when the cataract was formed.

But the scablands are erosional in origin, while the braided stream pattern is depositional.

The evidence for the origin of channeled scabland by stream erosion is overwhelming. The evidence of contemporaneity of action of all channels of a given tract, at least in its early history, is equally convincing. The only sequence indicated is that of development of the greater channels later in the epoch and consequent draining off of the shallower channels.[1] The scablands of the plateau in Washington are the beds of huge river courses in which

[1] Especially well shown in Lower Grand Coulee, in Moses Coulee between Palisades and Spencer, in The Potholes and Frenchman Springs south of Trinidad, and in Palouse Canyon south of Hooper, in all of which cataract recession in main channels cut off smaller channels alongside in the same scabland tract.

the streams once spread completely from side to side and only later became concentrated in the deeper canyons.

FIG. 8.—A part of Rock Creek (Lincoln County) and its associated scabland. The creek in the main channel is margined by vegetation. The scabland to the left is barren and the irregularity in lighting is due almost entirely to the cliffs which border the shallow anastomosing channels. (Aeroplane Photo by F. H. Frost.)

ALTITUDES AND GRADIENTS OF THE SCABLAND TRACTS

The heads of scabland tracts which are open to the basalt plain range in altitude between 2,350 and 2,500 feet above tide. There are six or eight of these, the number depending on just what is considered to constitute an individual scabland tract. At least the following should be recognized as unit tracts. The order in the list is from east to west.

1. Pine Creek channel. Altitude of head, 2,450 feet A.T.
   Gradient approximately 25 feet per mile
2. Cheney-Hooper tract
   Four heads:
   a) Marshall-Spangle, altitude, 2350±
   b) Four Lakes, altitude, ?
   c) Medical Lake, altitude, 2,425
   d) Deep Creek, altitude, 2,350±
   Total width of the group is 22 miles

Gradients:
  Spangle to Hooper, 21.9 feet per mile
  Cheney to Hooper, 22.6 feet per mile
  Medical Lake to Sprague, 24 feet per mile
  Medical Lake to Hooper, 22.5 feet per mile

3. Reardan channel. Altitude of head, 2,500+
   Gradient, Reardan to Odessa, 20 feet per mile
4. Davenport-Harrington channel. Altitude of head, 2,450±
   Gradient:
   - Davenport to Harrington, 27 feet per mile
   - Harrington to Odessa, 26 feet per mile
5. Telford tract
   - *a*) Eastern head. Altitude, 2,500±
     Gradient:
     - Rocklyn to Odessa, 30 feet per mile
     - Rocklyn to Krupp (Marlin), 26 feet per mile
   - *b*) Western head. Altitude, 2,500±
     Gradient:
     - Near Creston to Krupp (Marlin), 32 feet per mile
     - Near Creston to Wilson Creek, 30 feet per mile

     Total width of heads is 17 miles
   - *c*) Wilbur branch
     Gradient:
     - Creston to Wilson Creek, 32 feet per mile
     - Wilbur to Wilson Creek, 25 feet per mile
     - Almira to Wilson Creek, 26 feet per mile

The only scabland tracts which do not open on the basalt plain are Grand Coulee and Moses Coulee. For the head of Moses Coulee there are no altitude measurements. Grand Coulee has had a peculiar history, not yet fully deciphered, but the significant altitude at its head for present purposes is not the coulee floor (1,530 feet A.T.) but the scabland margining the brink of the canyon, about 2,500 feet A.T. The canyon has been cut subsequent to the first spilling over of glacial waters. The floor near Coulee City is 1,510 feet A.T. Most of this descent occurred within a few miles of Coulee City, the original slope being as steep as 20° in part and averaging perhaps 10° for 1,000 feet of descent. This is the chief reason for the great canyon across the divide. No other scabland head has been notably canyoned. None other had a gradient to exceed about 30 feet to the mile. All the canyons of the channeled

scablands are located in places of exceptionally steep original gradients.

If the channeled scablands are the product of stream erosion, and if all tracts are of the same age, the fact that the scabland heads vary in altitude, though all but two are open to the same glaciated basalt plain, can have but one satisfactory explanation. Each glacial stream must have had a source of water which was unconnected with the others. This means that the ice sheet whose melting yielded these streams must have covered the basalt plain and in most places must have been in contact with the mature loessial hills which separate the scabland heads. It means, furthermore, that but a few miles of ice front supplied the water for streams so huge that they flooded over many preglacial divides of the mature topography even in the southern part of the plateau. It was this flooding across divides which produced the scabland plexus of the plateau.

About 40 miles of ice front in one case[1] yielded water sufficient to denude a non-elongated tract 250 square miles in area of a loessial cover about 100 feet in maximum thickness. This was done by lateral planation in the preglacial drainage lines of the tract. These lines were so shallowly intrenched in the basalt and the volume of the water was so great that, as the loessial hills were eroded away, the flood spread over the entire area, 13 miles wide. Gradients were low, however, and it did not develop canyoned channels. Steeper gradients farther from the edge of the ice, and greater capacity of the preglacial valleys, held the waters within the confines of these valleys, but six such[2] were necessary to contain the flood and they were all greatly eroded in the underlying basalt.

Another large scabland area[3] is 75 miles long and 15 miles in average width. Its total descent is 1,850 feet. Its altitude at the head is the lowest of all such tracts. It differs from the one above in its notable linear extent, in the possession of a large number of isolated groups of loessial hills of the older topography, in its greater

[1] The Telford scabland and its dependencies.

[2] Coal Creek, Duck Creek, Lake Creek, an unnamed creek, Connawai Creek and Wilson Creek.

[3] The Cheney-Hooper area, extending from Spangle and Cheney to Snake River, south of Hooper.

gradient and in the development of canyons.[1] Though a much greater volume of water passed through this tract, the gradients were steep enough to draw off the flood and prevent a complete spreading over the area. Much water came to it from the ice margin to the east in Idaho and no estimate can now be made of the length of ice front which contributed to it. There were five or six places of distributary discharge where this flood crossed preglacial divides and one of them[2] eventually obtained most of the discharge. Along this distributary route, the glacial flood swept away the loessial hills for a width of 10 to 15 miles and eroded 500 feet into the basalt.

The glacial drainage route which possessed the highest crossing of the preglacial surface of the plateau is Grand Coulee. It also found the steepest gradient[3] and its volume was sufficient with this gradient to cause the deepest erosion in the basalt. Upper Grand Coulee, across the preglacial divide, is 1,000 feet deep. But its floor, after the epoch had closed, was lower than that of any other glacial drainage route at the head. In its early history it drew water from about 40 miles of ice front, but never spread widely. The gradient, determined here by exceptional warping of the basalt, prevented that. There was no noteworthy preglacial stream along its course. Grand Coulee is, therefore, the simplest but grandest case of canyon-cutting by glacial streams on the plateau.

DEPTH OF GLACIAL STREAM EROSION IN THE SCABLANDS

Criteria.—The courses of the larger valleys in the mature drainage system were determined by the warped surface of the basalt. The dominant feature of this warping is the southwestward dip from Spokane River and Columbia River on the north to Snake River on the south and Columbia River on the west. Many minor folds are superposed on this dip slope, so recent geologically that anticlines determine divides and synclines contain stream valleys.[4] Commonly, only the major valleys are intrenched in the

[1] Cow Creek, Rock Lake, and Creek and lower Palousė River now occupy the most striking of these canyons.

[2] Palouse River Canyon below Hooper.

[3] In one place, 1,000 feet in about a mile.

[4] Examples are Moses Coulee east of Palisades, Wilson Creek above Almira, Crab Creek below Corfu, Washtucna Coulee, Lind Coulee below Lind, Snake River near Lewiston and Clarkston, Union Flat Creek, Rebel Flat Creek, and Palouse River above Winona.

basalt. The minor valleys, in general, are not eroded through the loessial mantle.

Except near the bounding canyons of Spokane, Columbia, and Snake Rivers, or in exceptionally upwarped parts of the plateau, the preglacial valleys in basalt which were unviolated by the glacial flood, have the same mature slopes as those in the loess. Where glacial streams found routes eroded but slightly in basalt, they commonly spread widely at first[1] and only later eroded canyons, if they did so at all. Such wide scablands commonly are bounded by steep bluffs of loess. Many of the mature valleys in basalt were sufficiently capacious to contain the glacial waters which entered them. In such cases[2] the scabland of the route lies on the sides and bottoms only, and unsteepened slopes of the bounding older topography may come to the edge of the scabland. Such a tract is narrow and instead of having a multitude of lateral shallow channels anastomosing with the main canyon, it consists of exceedingly roughened ledges of basalt outcropping on the slopes of the main valley. Shoulders in the curves of these valleys were treated with especial vigor, in some cases being wholly cut away to leave prominent cliffs on the valley walls.

By smoothing out these ledges, something of the cross-section of the preglacial valley may be obtained. Remnants of the old floors are recorded in isolated buttes of basalt on the present floor and in the lowest prominent rock terraces, below which is the canyoned channel eroded in mid-current by the huge glacial stream.

Instances.—In Cow Creek, southwest of Ralston, the remarkable number of knobs and buttes in the lower part of the valley indicates clearly that the preglacial floor must have been at least 75 feet higher than the present. In Crab Creek Valley, between Krupp (Marlin) and Stratford, there are prominent buttes, isolated or partially isolated on the floor of the canyon. The tops of these are remnants of the preglacial floor and their height (100 feet in places) is a minimal measure of the depth of canyon-cutting by the glacial waters.

[1] As in the Telford and the Cheney-Hooper areas.

[2] Washtucna Coulee, Esquatzel Coulee, Lower Moses Coulee, Lind Coulee, Pine Creek above Rock Lake, Rock Creek (Lincoln County) and Coal Creek are examples.

In Washtucna Coulee, numerous prominent rock terraces from 150 to 200 feet above the present floor are probably remnants of the earlier valley bottom. In Esquatzel Coulee, into which Washtucna opens, these terraces are 200 feet and more above the bottom.

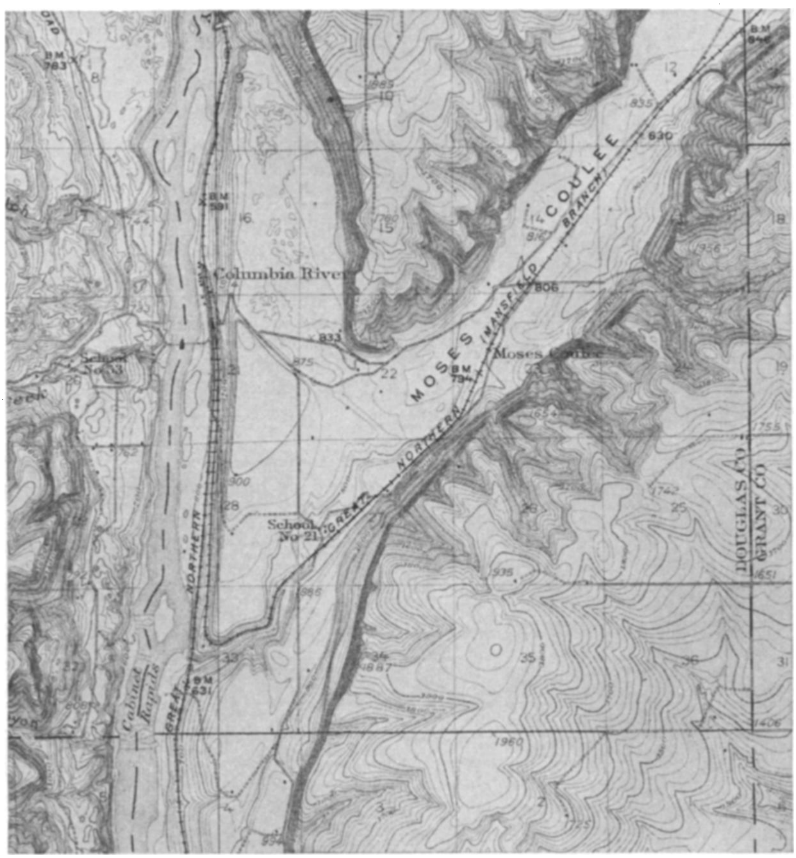

FIG. 9.—The lower part of Moses Coulee. Part of Malaga, Washington, topographic map. Note truncated spurs, hanging ravines, alluvial fans, and the great terrace in both Moses Coulee and Columbia Valley.

In Lower Moses Coulee (Fig. 9), the mouths of preglacial tributary ravines hang approximately 400 feet above the rock floor. Some of this discordance of grade is due to widening of the preglacial coulee, which here was a canyon, by the glacial stream but probably most of it is due to deepening during the glacial epoch.

In addition to the deepening of valleys already existing, the glacial flood actually made, *de novo*, drainage ways of greater width and depth than any previously developed on the plateau. This happened where divides were crossed and unusually high gradients down the farther slopes were found. Five such places are especially noteworthy: Devils Canyon, Palouse Canyon below Hooper, Drumheller Channels, Othello Channels, and Grand Coulee.

Preglacial Palouse River joined Snake River at Pasco, its subparallelism with the larger stream for 150 miles being structurally determined. The glacial flood from the north entered it in midlength at several places between Winona and Washtucna. The volume of this flood was more than the valley could carry away.

FIG. 10.—Devils Canyon, cross-section a mile and a half south of Kahlotus, showing (1) steepened loessial bluffs (33°), (2) narrow scabland above brink of basalt cliffs (3) canyon 450 feet deep and less than one-fourth mile wide, and (4) post-Spokane talus, three-fourths the height of the cliffs. Horizontal and vertical scale the same.

Two leaks across the divide to the Snake developed, one near Kahlotus, and one near Hooper, and in both very great gradients were encountered.

The Devils Canyon distributary, south of Kahlotus, cut 50 feet or so through the loess and then by recession of waterfalls over ledges of basalt in the north slope of Snake River Valley, it eroded a canyon 5 miles long, a quarter of a mile wide and 500 feet deep (Fig. 10). Every fall but the lowest retreated completely through the divide. The remaining ledge, like a dam separating the two canyons, is less than 100 feet above the floor of Washtucna Coulee and not half a mile wide.[1] An abandoned half of a double cascade stands in mid-length of Devils Canyon (Fig. 4).

[1] The Spokane, Portland and Seattle Railroad tunnels through this ledge. In 1916, Washtucna Lake was so high for a time that it overflowed through this tunnel into Devils Canyon.

A much larger volume of water spilled across the preglacial divide south of Hooper. Before the great canyoned channel now transecting this divide had been eroded, the stream was 10 to 15 miles wide. Several channels of canyon proportion were initiated, but one outran the others in its deepening and finally secured all the discharge. Many of the shallower canyons enter the southern part of the main one over abandoned waterfalls. These channels could have carried water only when the wide scabland of the divide had no deep canyon completely across it. Their falls could have developed only after a deep main canyon existed *below* their junction. It follows, therefore, that Palouse Canyon was cut by retreating waterfalls, though these were destroyed later in the epoch. One only survived, now notched considerably by the post-glacial work of the Palouse River. The falls today are 198 feet high. Palouse Canyon is another Devils Canyon in all save its greater width and the fact that the preglacial divide was cut entirely in two.

Drumheller Channels and Othello Channels are two remarkable cases where the glacial flood crossed anticlinal ranges.[1] In both, the anticline is asymmetrical and the waters flowed down the gentle slope. In both, the flood at first was wide but became concentrated later in the deepening canyons. The maximum depth of erosion in Drumheller Channels was 400 feet, about 100 feet of which was in a weak sedimentary formation (probably the Ellensburg), and 300 feet in basalt (Fig. 11). The width of the Drumheller denuded tract is about 10 miles. This particular scabland area has a more striking and more complicated development of channels and rock basins than any other on the plateau. It is the only area of this type now topographically mapped. Below the Channels, along the northern flank of Saddle Mountains, the ancient river eroded 300 feet into the broader scabland.

But Drumheller Channels is not wholly the product of the glacial flood whose history we have been following. It and the main canyon of Grand Coulee carried drainage from a later ice sheet, and it has carried Crab Creek since the later glacial epoch. The amount of deepening during each Pleistocene epoch is diffi-

[1] Drumheller Channels crosses the eastern nose of Frenchman Hills anticline, Othello Channels crosses the eastern nose of Saddle Mountains anticline.

cult to determine. Othello Channels carried less water than Drumheller Channels, consequently is a smaller tract. Furthermore, it received water during only the earlier epoch. The degree of development of its canyons and rock basins is comparable to that of the larger tract and makes it probable that most of Drumheller Channels were formed during the earlier epoch.

The features of Grand Coulee are of such magnitude and its history so complicated by local conditions that an entire paper might well be devoted to it. It affords the greatest example of canyon-cutting by glacial streams, not alone for the Columbia Plateau, but for the world. The field evidence indicates that no preglacial drainage route ever existed here. Scabland with shallow channels margins the upper part of the Coulee, though 1,000 feet higher than the adjacent coulee floor, and there are no tributaries in the mature topography such as are possessed by Lower Moses Coulee and Washtucna Coulee. A glacial river, 3 miles in minimum width, spilled southward here over the divide and down a steep monoclinal slope. Judging by present grades and altitudes of this structural slope, the stream descended nearly 1,000 feet on a grade of approximately 10°, a few miles north of Coulee City. Such a situation is unparalleled, even in this region of huge, suddenly initi-

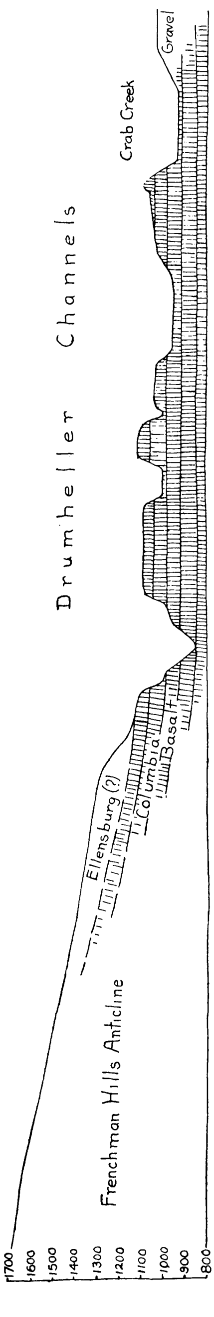

FIG. 11.—Cross-section of the head of Drumheller Channels, showing (1) structure at eastern nose of Frenchman Hills anticline, (2) the pre-scabland topography, and (3) the scabland channels. Probably no preglacial drainage crossed the anticline at this place. The lower 50 feet of the deepest channel is a rock basin.

ated, high-gradient rivers. Across this monocline between Columbia River and Coulee City, the canyon is 30 miles long and averages all of 2 miles in width and 800 to 900 feet in depth. In the making, at least 10 cubic miles of basalt were excavated and removed. Though a later flood of glacial waters used this route,[1] it did but little to deepen it.[2] By far the greater part of the erosion of Upper Grand Coulee was performed by the earlier glacial stream. It is very probable that this immense task was performed by the stoping of cascades and cataracts which retreated entirely through the monoclinal uplift to the deeper valley of Columbia River and thus left the great notch.[3]

It also seems probable that when the retreat of the ice sheet began, the plateau west of Grand Coulee was abandoned last. Earlier clearing of the Spokane and Columbia valleys to the east allowed all the drainage of the ice sheet to use the Grand Coulee route, which was then the lowest of all. Grand Coulee's greatest flood and probably its greatest erosion thus came after the other scabland routes had gone dry.

VOLUME OF THE GLACIAL STREAMS

If the channeled scablands of the Columbia Plateau are the erosive results of glacial waters, certain statements as to the volume of the streams can be made. Measurements are possible if remnants of the preglacial floor of the main valley exist in places where the valley brimmed over with the glacial flood to produce distributary courses. Should it appear that the amount of canyon-

[1] During the Wisconsin glaciation.

[2] Grand Falls, below Coulee City, consists of Dry Falls, Deep Lake Falls and a smaller unnamed falls a mile east of Deep Lake. The lip of the smaller falls is 125 feet higher than the floor of the channel leading to Dry Falls. Yet all were made by the same glacial stream and only Dry Falls and Deep Lake Falls were used and modified by the later discharge.

Furthermore, the Wisconsin ice did not cross Spokane River or Columbia River east of Grand Coulee and its waters were free to use the lowest of the ten earlier routes. Only Grand Coulee was so used, showing that it had been eroded by the earlier discharge to a depth not far short of that which it now has.

[3] This inference has no physiographic evidence in Grand Coulee to substantiate it, but is based on the known procedure of the glacial streams in similar situations, e.g., Lower Palouse Canyon, Devils Canyon, Frenchman Springs, and The Potholes.

cutting by these glacial streams has been overestimated, the depth of the stream to flood across the divide must be correspondingly increased. This view promptly runs into an absurdity, for the less the canyon-cutting is held to have been, the deeper and therefore more competent to erode the stream must have been.

One of the best cases for measurement is Washtucna Coulee at the head of Devils Canyon. Though there are but two small rock knobs out in the coulee floor, the summit of neither indicating the original valley bottom, there are good rock terraces to record it (Figs. 12 and 13). Near Kahlotus they lie 1,000 to 1,200 feet above tide. The glacial stream here, at the beginning of its history, overflowed through the loessial hills to Snake River, at an altitude of at least 1,350 feet. It was, therefore, from 150 to 350 feet deep. Its width averaged at least a mile.

And this was no ponded condition, for Washtucna Coulee opened widely into Esquatzel Coulee, an even more capacious valley, and Esquatzel in turn into Columbia and Snake valleys, and the glacial waters cut deeply into the bottom of both coulees. Figuring the preglacial floor as 1,000 feet A.T. at Kahlotus and as 675 feet A.T. at Eltopia, 34 miles farther down the valley, the great glacial stream had a gradient of about 10 feet to the mile.

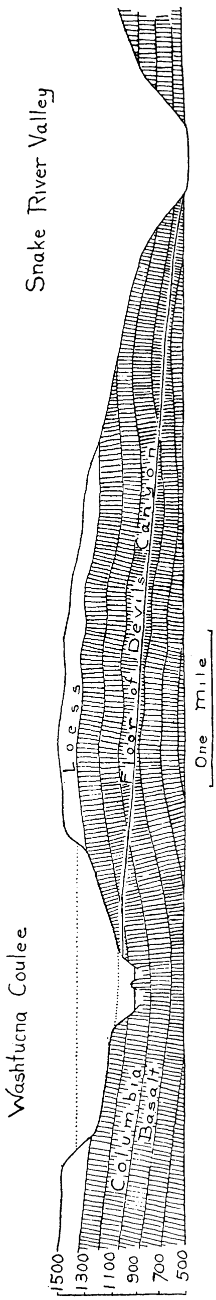

FIG. 12.—Cross-section of Washtucna Coulee and Snake River Valley, with longitudinal profile of Devils Canyon, showing (1) structure of the basalt, (2) its loessial cover, (3) rock terraces flanking Washtucna (Kahlotus) Lake, remnants of the preglacial valley floor, (4) the inner canyon eroded by the glacial stream, (5) steepened slopes of the loess, facing the coulee, and (6) approximate upper limit of the flood which spilled across to Snake River.

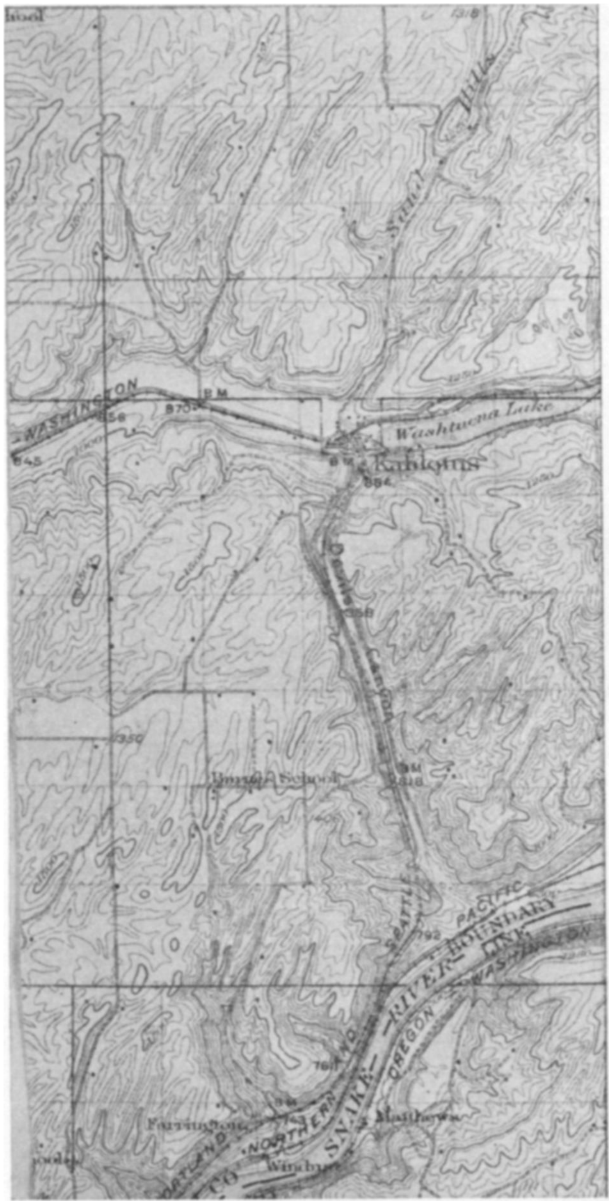

FIG. 13.—Devils Canyon. Part of Connell, Washington, topographic map.

Further evidence that glacial waters so filled Washtucna Coulee that the former valley became simply a channel is found in the upper limit of glacial stream gravels and of scablands. At the head of Devils Canyon, the highest scabland is 1,250 feet A.T., 250 feet above the brink of the cliffs of the canyoned channel. At Estes, a gravel bar deposited by the glacial stream lies 250 feet above the Coulee floor and about 125 feet above the rock terrace which marks the old valley floor. Near Sulphur, the highest scabland surface, at the base of the steep loessial bluffs, is between 1,100 and 1,150 feet A.T., 100 to 150 above the rock terrace. Northwest of Connell a terrace of sand and fine gravel lies at 1,000 feet A.T. It marks the upper margin of the scabland here and probably is a deposit of the glacial stream. It is 100 feet above the broad rock terrace. The canyoned channel here is cut 150 feet below the rock terrace.

Crab Creek Valley, below Odessa, received more water than it could carry away, at least before its central canyon had been eroded. It overflowed southwestward, by way of Black Rock Coulee and its associated scabland, to the Quincy Basin which Crab Creek itself entered farther north. Measurements here are only approximate but they indicate the order of magnitude of this glacial stream. Scabland and glacial stream gravel along the southern edge of Crab Creek Valley lie 300 feet or more above the present stream and extend a mile and a half back on the upland from the margin of the preglacial valley. This valley had been canyoned more than 100 feet by the glacial stream which, on the basis of these figures, was 200 feet deep at its inception.

The Telford scabland tract, 13 miles wide and 20 miles long, has been swept almost completely bare of the loessial deposit. The relief in a cross-section of the basalt surface now exposed, aside from the minor canyons, is about 50 feet. To have been so denuded, this tract must have had a sheet of running water of this depth completely over it.[1]

[1] That the ice sheet did not advance over the Telford denuded tract is shown by the presence of a few isolated loessial hills with characteristically steepened marginal slopes. One such group lies 7 or 8 miles north of Telford. It has a maturely eroded topography and a dark loessial soil without rock fragments of any kind. But it is cut by channels of glacial waters which eroded to the basalt. The fact that these waters went through the group, though the surface immediately north of them drops off into the deep canyons of Hawk Creek, a tributary of Spokane River, proves that glacial ice must have crowded up against the northern side of the group.

Further evidence of the depth of the glacial streams will be presented under the next subject.[1]

DEPOSITS MADE BY THE GLACIAL STREAMS

The record of Pleistocene glacial streams almost everywhere is one of aggradation. Glacialists commonly think of the subject only in such terms, textbooks discuss it only in that light; it is the orthodox conception. But in the Columbia Plateau exceptional factors controlled. The preglacial valleys in general were small and of relatively high gradient, the volume of the glacial streams was very great, the amount of detritus from the ice was very small, and the rock crossed was either loess or closely and vertically jointed basalt, both of which yielded rapidly to the torrents. The result of these conditions was great deepening of the valleys, and deposits made by the streams are of minor importance. Their character, however, adds to the weight of evidence already presented for the origin of channeled scabland by glacial stream erosion.

The deposits are almost wholly of gravel. Sand is a minor constituent and clayey material is lacking. The gravel and sand are almost wholly of basalt, though all deposits contain fragments of rock foreign to the plateau. The basaltic gravel is not well rounded though most of it is sorted and stratified and indubitably of stream origin. Foreset bedding is common, the direction of dip according with the slope of the scabland tract. In some places, the deposits are composed of very coarse material, with abundant, sub-rounded, basaltic bowlders 3 and 4 feet in diameter. These were originally bowlders of decomposition and were derived from flows with particularly large columns, underlying or in the immediate proximity of the deposit. Where a few erratic bowlders are associated[2] the deposit itself might be misinterpreted as a bowldery till.

The gravel deposits rest on irregularly eroded basalt, essentially a buried scabland surface. Nowhere do they lie on or beneath the loess. Neither the gravels nor the underlying basalt are

[1] If these enormous streams all came to the Columbia eventually, should not the great volume be recorded farther down the master stream? The writer has seen enough to convince him that it is so recorded, and hopes to publish on this subject in the future.

[2] As west of Lantz, for example.

decayed.[1] Cementation with calcium carbonate has begun but has not advanced far.

Most isolated loessial hills in a scabland tract have a deposit of gravel depending from their down-gradient end. Many knobs and buttes of basalt have similarly situated gravel deposits.

In many cases, the gravel deposits constitute discontinuous terraces on the margins of the scabland tracts, suggesting remnants of former valley fills.[2] But the evidence seems conclusive that all gravel deposits of the scablands are bars, built in favorable situations in the great streams which eroded the channels.

The rounded profiles and ground plans of many gravel deposits in the scablands are in accord with this interpretation. The unfilled canyons and rock basins, in intimate association with the discontinuous gravel deposits, indicate clearly that both are products of the same episode. The only alternative hypothesis is that channeled scabland was formed, then buried in gravel, then in large part re-excavated by streams little short of the magnitude of those which eroded the scablands. This has no other field evidence to support it and requires a much more complicated history. Furthermore, such deep canyons were cut when the scablands were made, and such noteworthy divide crossings were made that a reoccupation of all the scablands by glacial drainage from a second ice sheet would be impossible. And the hypothesis of dissection by the postglacial streams of the scablands is quite inadequate. Lakes and pools still stand in the rock basins on the channel floors, almost as they were left by the glacial flood.

Gravel deposits in the deeply canyoned scablands occur on the broad upper scabland surfaces, on the roughened slopes of the preglacial valleys and down in the canyons. The interpretation of these deposits as bars requires no change in general conditions, as does the alternative hypothesis; it simply requires that gravel be deposited locally as conditions might favor, all through the

[1] Local exceptions, as 1 mile southwest of Lamont, where ground water has been especially active.

[2] So the terraces in Pine Creek channel were interpreted in the earlier paper by the writer. That view is here abandoned for one much more consistent with all other features of the scablands.

epoch of erosion of the basalt. Deposits on the highest scablands[1] were made before the deepening canyons drew the waters into more restricted routes. Deposits in the deeper portions[2] were made during the latest stages of the episode. No gravel deposits were ever as thick as the rival hypothesis would require them to be.[3] That view demands that the canyons be eroded, then filled completely *with their own dêbris*, then re-excavated in large part.

However, there are two places on the plateau where the history of deposition by glacial streams has been somewhat different. One of these is Hartline gravel flat, the other is Quincy Basin. Both are structural depressions, not completely filled before the glacial floods arrived. The Hartline structural valley became filled with dêbris from the cutting of Upper Grand Coulee before Lower Grand Coulee had been eroded. The trenching of the lower coulee, and particularly the development and retreat of Grand Falls, incised the southern rim of the valley so that, by the close of the episode, the gravel fill, once the floor of the glacial stream, had been removed in its western part, and the remnant left 200 feet or so higher than the brink of Grand Falls.[4] The total fill in the Hartline structural valley is about 250 feet. It is composed of bowlders, cobbles, and gravel near Grand Coulee, and of sand 5 or 6 miles east, back from the main drainage line. An old channel from Grand Coulee crosses its northern and eastern part and leads into Deadmans Gulch, a distributary which spilled across the southern rim into Spring Coulee before Lower Grand Coulee had developed into the dominant notch that drained and dissected the flat. The terrace form of Hartline flat is the result of erosion of a once complete gravel fill. Its scarp is not constructional, as are those of bars. But the fill and the subsequent erosion occurred because of special local conditions, not because general conditions changed.

[1] As about Gloyd along the Black Rock distributary from Crab Creek Valley.

[2] As at the mouths of Duck Creek and Wilson Creek in Crab Creek Valley and at the junction of Crab and Coal creeks.

[3] For example, gravel deposits north of the town of Washtucna lie on the slopes of the coulee, 350 feet above the present floor. They antedate the deeper canyoned portions of the coulee.

[4] Estimated from the surviving eastern member of that complex waterfall, the only part which escaped modification by the Wisconsin glacial stream.

Quincy Basin, like the Hartline Valley, does not have a scabland floor. Both lay too low to be eroded. But both belong to the glacial drainage plexus. Quincy Basin probably contains more gravel than all the scablands of the plateau together. It was an enormous settling basin for the glacial rivers from Grand Coulee and Crab Creek. The flood of waters entering it was so great that at first three discharge ways were simultaneously in operation.[1] The southern and larger one obtained all the discharge later, and by deep notching of the basin's rim, caused the glacial waters which traversed the fill to incise their deposits. Two great channels and one smaller one were thus formed. The two large channels are each about 3 miles wide. Each was eroded about 100 feet deep during the later part of the episode. The one which contains Rocky Ford Creek also carried the later Wisconsin discharge and was further modified then.[2]

Erratic bowlders, some of them striated, are widely distributed at all altitudes on the basalt plain and the scablands. They also occur in valleys of the mature topography which open northward on to the basalt plain, and in some which open on to scabland tracts. The size, angularity, and striated surfaces indicate that these erratic bowlders were not rolled to their positions by running water. In the scablands, they must have been carried by berg ice on the great rivers. In their peculiar and limited distribution in the valleys in loess is evidence of small glacial lakes, in which the drift-bearing bergs floated.[3]

[1] Frenchman Springs, The Potholes, and Drumheller Channels.

[2] This interpretation is a modification of that published earlier by the writer. Further study of Grand Coulee, Quincy Basin, and Drumheller Channels has led to a magnification of the work of the earlier flood, and a minimizing of the results accomplished during the Wisconsin epoch. Grand Falls is now considered to be a pre-Wisconsin affair, none of the distributary canyons of Grand Coulee, except Dry Coulee, are thought to have functioned during the second flooding, the Adrian terrace is considered to be a part of the original fill and not of Wisconsin age, and all the deep canyons of Drumheller Channels are thought to date back to the earlier episode.

[3] Below an altitude of about 1,250, erratic bowlders occur on every formation and type of topography on the plateau. But these are a younger deposit (see *Journal of Geology*, Vol. XXVII [1919], pp. 489–506) and do not much overlap the scablands. Where overlap does occur, however, it is impossible to distinguish bowlders of the two categories by any difference in the amount of decay.

DEPTHS OF SNAKE AND COLUMBIA VALLEYS DURING THE EPOCH

Evidence on this question may be obtained at the debouchure of glacial drainage routes into these master valleys. Five of the nine such debouchures will be examined.

The rock floor of Moses Coulee is fully as low as that of Columbia Valley at the junction of the two. Both contain a great gravel fill here. Columbia River has cut through it, a depth of more than 300 feet. There is no such trenching in Lower Moses Coulee, but a well at Appledale penetrates 300 feet of this gravel without encountering bedrock.

The two cataracts of The Potholes and Frenchman Springs, which operated in the early part of the epoch, descended nearly the full height of the present Columbia Valley walls there. At The Potholes the glacial cataract can be traced down to less than 200 feet above the present Columbia (Fig. 7).

Koontz Coulee, 20 miles north of Pasco, is cut in the weak Ringold formation. It is 250 feet deep and a mile wide. It is floored with basaltic stream gravel from the scablands farther upstream. Though the Ringold silts extend down to the level of the Columbia at this place, the mouth of the glacial river channel hangs 200 feet above. No cataract could have been maintained here, as was done at The Potholes and Frenchman Springs, and the level of the Columbia of this epoch at this place is thus clearly recorded.

At the mouth of Palouse River, there are two parallel canyons in the scabland, one containing the river, the other dry. A basaltic butte separates them. It stands nearly in the center of the valley and its summit is between 350 and 400 feet above Snake River. It is a part of the original north wall of Snake River Valley, over which the gigantic cascade tumbled when the glacial flood broke across the preglacial divide from the north. This "Goat Island" testifies to the existence of a Snake River Valley at this place as deep then as now.

THE GLACIATION

Because the record of the ice sheet, from which came the streams that made the scablands, is best preserved on the basalt plain about the city of Spokane and along the south side of Spokane River,

this has been named the Spokane glaciation.[1] It assuredly is not an early phase of the Wisconsin glaciation. That is recorded by pronounced moraines on the plateau west of Grand Coulee, in Columbia Valley north of the mouth of Spokane River, and in Colville Valley north of Spokane River. The Spokane ice left no terminal moraine and very little ground moraine. The reverse relation exists regarding the glacial waters of the two glaciations, for the Spokane glacial waters were of prodigious quantity and the Wisconsin waters of little consequence. Furthermore, a long time elapsed between the two glaciations as shown by the relative volume of talus accumulations in tracts swept by glacial streams of the two epochs. Post-Spokane talus in almost all places stands three-fourths to four-fifths of the total height of the basalt cliffs, post-Wisconsin talus stands about halfway up on the cliffs of Grand Coulee.[2]

For the absence of a terminal moraine along the southern edge of the area reached by the Spokane ice sheet, the writer has as yet no satisfactory explanation. It seems clear, however, that a moraine never was deposited, rather than that it was once built and subsequently removed. The functioning of some scabland tracts absolutely required glacial ice against the north slopes of the unglaciated hills at their heads. Floated granite erratics among some of these hills also require blocking of valleys by glacial ice. Yet there is no evidence of lateral drainage along the ice front in contact with the unglaciated hills, to which might be ascribed the removal of a terminal moraine.

The Spokane glaciation cannot be dated very far back in the Pleistocene, else the scablands should have a soil mantle of eolian sand and dust and disintegrated basalt, and the hundreds of lakes in the old channels should have been destroyed.

Leverett has suggested that a pre-Spokane till beneath loess at Cheney is of Kansan age.[3] If it is, and if the post-Spokane glaciation is correctly ascribed to the Wisconsin epoch, the Spokane

[1] J H. Bretz, "Glacial Drainage on the Columbia Plateau," *Bulletin of the Geological Society of America*, Vol. XXXIV (1923), pp. 573–608.

[2] This question of differentiating Pleistocene epochs by talus accumulation will be discussed more fully in a separate paper.

[3] Frank Leverett, *Bulletin of the Geological Society of America*, Vol. XXVIII (1917), p. 143.

glaciation should be either Iowan or Illinoisan in age. Farther than this, the writer does not care to go. Ordinary criteria in use east of the Rocky Mountains for differentiation of drift sheets cannot safely be used for the correlation of these glaciations in Washington. The only one relied on here is the moraine-building habit of the Wisconsin ice sheet, a character which seems to have been world-wide.[1]

There were no channeled scablands on the Columbia Plateau before the Spokane glaciation. A mantle of loess, with a mature topography, completely covered it. The evidence for this conclusion is found in the great and remarkably persistent width of the Cheney-Hooper scabland tract throughout a length of 70 miles, and the various distributary courses out of it, some of which never were eroded to the basalt. These features never could have been formed, had spillways like those of the present existed. But with early escape southward retarded by the loessial hills and their small drainage ways, a wide spreading among them necessarily occurred, and some distributaries were able to cross to Crab Creek drainage.

A puzzling situation regarding glacial drainage exists in the vicinity of the small Spangle lobe. There is no adequate drainage route around it for glacial waters which came from Idaho and western Montana and entered the Cheney-Hooper scabland tract. Two spillways exist north of Mica, between Lake Spokane[2] east of this lobe and Pine Creek channel. Both have erratics in them, the highest at 2,550 feet A.T., but neither carried much water. There is no error involved in mapping this lobe because an ice dam at Spangle is required for the operation of the Pine Creek channel. This channel carried far more water than the Mica spillways, water derived directly from the Spangle lobe. Yet it also is inadequate for the drainage in question. And much more water went down the Cheney-Hooper scabland tract, in proportion to the immediately tributary ice edge, than passed through any other

[1] No till or other evidence of pre-Spokane glaciations has been found beneath the loess (save only the Cheney deposit). No till has been found in the scablands. The writer is unable to agree with J. T. Pardee who states (*Science*, Vol. LVI [December 15, 1922], pp. 680–87) that till occurs at "scores" of places on the plateau south of the limit of Spokane glaciation, as mapped in Plate III.

[2] Thomas Large, *Science*, Vol. LVI (September 22, 1922), pp. 335–36.

scabland tract except Grand Coulee in its later stages. It seems necessary, therefore, to assume a prominent *subglacial* drainage line, across the area covered by the Spangle lobe. This is best located along the preglacial valley of Lake (Marshall) Creek and the rock basin of Farrington (Fish) Lake. Out of this rock basin, just beneath the edge of the ice, the waters from the east emerged and joined those coming directly from the ice.

If the battle between the diluvialists and the glacialists, out of which has emerged our conception of Pleistocene continental glaciation, had been staged in the Pacific Northwest instead of the Atlantic Northeast, it seems likely that the surrender of the idea of a debacle might have been delayed a decade or so. Fully 3,000 square miles of the Columbia plateau were swept by the glacial flood, and the loess and silt cover removed.[1] More than 2,000 square miles of this area were left as bare, eroded, rock-cut channel floors, now the scablands, and nearly 1,000 square miles carry gravel deposits derived from the eroded basalt. It *was* a debacle which swept the Columbia Plateau.

[1] Except in the Hartline and Quincy structural depressions.